A Reference Guide on Stormwater Related Topics

for Naval Public Works Officers

BY
Nicholas Merry, PE

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ABSTRACT

Naval Civil Engineer Corps Officers assigned to Public Works billets often have no background dealing with stormwater. Since stormwater is only one of many issues on their plate, they need a basic reference tool that highlights and discusses stormwater related issues. This report attempts to act as the reference tool that addresses issues important for Naval Officers assigned to Public Works.

This report focuses on three primary areas. Officers need to know the laws governing their installation, therefore, legal concerns are addressed with a brief history, federal requirements and state requirements. They must also address the issue of the quality of water leaving the base, therefore, both preventative measures and control measures are presented for best management practices. Lastly, the report includes a discussion on maintenance of existing stormwater conveyance systems since this typically requires significant planning and resources and, a serious failure in this area results in a telephone call from the base Commanding Officer. Several topics contain further references available on the world wide web to provide readily for additional information.

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1. INTRODUCTION

Stormwater control systems are critical Naval facilities infrastructure components. Management of these systems is a complex process due to requirements for continual maintenance and the extensive regulations governing stormwater. The Navy frequently rotates Civil Engineer Corps Officers through Public Works, Construction Contracts Administration, Seabees and staff billets every two to three years. Therefore, Officers are typically assigned to positions that manage stormwater related systems with little or no stormwater background.

Numerous references exist dealing with the many aspects of stormwater management. Although comprehensive, these references are large and typically require extensive research to answer even simple problems. This report attempts to cover topics most relevant for an Officer assigned to a public works billet and it is intended to provide a tool for Officers assigned to public works billets who are new to the stormwater arena. However, it can also serve as a convenient reference for professionals with any level of experience in stormwater management. I will cover some of the basic issues involved with stormwater, providing a synopsis of issues and presenting current ideas and techniques.

One of the first concerns of all Officers managing stormwater programs should include legal and regulatory requirements. This paper provides an overview of applicable laws, regulatory agencies and how they apply to stormwater management. The quality of the stormwater leaving installations is another relevant concern. Therefore, requirements and options for improving the quality of stormwater outflows through best management practices are also presented. A third major concern discussed is maintenance of the existing infrastructure. A serious storm drainage failure is a quick way to get called in to the base

Commanding Officer's office. The age of existing facilities ranges from less than ten years to over one hundred, necessitating familiarity with several different types and degrees of infrastructure maintenance.

The report includes several internet addresses for sites that are sources of additional information on topics discussed. This is not meant to be a comprehensive document, but more of an overview that briefly discusses selected topics. Watershed Management is a topic associated with stormwater that is not discussed in this document; this issue becomes most significant when implementing modifications that result in changes to drainage. Public Works Officers assigned to bases undergoing significant new construction programs should evaluate the impacts on their local watershed. They should also identify any special legal requirements such as additional on site detention facilities.

2.0 LEGAL REQUIREMENTS FOR STORMWATER

Federal lawmakers are driving forces behind the efforts to clean up our nation's surface waters. The principal legislation passed by Congress governing stormwater pollution of the nation's surface waters is the Federal Water Pollution Control Act. Originally enacted in 1948, amendments passed in 1972 totally revised the Act to its current form, called the Clean Water Act. The Clean Water Act established ambitious programs to reverse the downward trend in water quality. These programs are continuing to grow as the courts and agencies work to implement Congress's intent to improve the quality of the nation's surface waters.

2.1 Brief Legislative History

The Clean Water Act of 1972 established the National Pollution Discharge Elimination System (NPDES) to stop the flow of pollutants into our nation's surface waters.

The Act gave the Environmental Protection Agency (EPA) the authority and responsibility to issue discharge permits for every point source discharger in the United States. The EPA used this legislation to focus on reducing pollutants discharged through municipal sewage and industrial wastewater outflows. Significant progress has since been made in cleaning up these sources of pollution.

Initially, the EPA recognized that stormwater outflows were point sources of pollution, but reasoned they were better handled at the local level. After several legal challenges and appeals, the courts ruled that the EPA could not exempt discharges at their discretion, but must permit all discharges. However, the EPA could determine the extent of permitting, for example, whether to require a full permit or allow for an area or general permit. After several additional legal challenges, in 1984 the EPA published final permit application requirements and deadlines for stormwater discharges.

The EPA only could implement these regulations for nine industries before Congress reauthorized and amended the Clean Water Act in 1987. These amendments, commonly called the Water Quality Act, specified a new national strategy for stormwater control. One important provision of this act created the National Storm Water Program (NSWP). Programs and regulations that resulted from the NSWP established the policies that guide today's stormwater management programs.

2.2 NPDES Phase I

In response to the NSWP requirements, the EPA established a two-phase program applying the NPDES to stormwater. This program incorporated a prioritized approach to managing stormwater pollution. The EPA used a phased approach to address the largest

sources of stormwater pollutants expeditiously, minimize the financial burden to smaller municipalities and evaluate the impacts of regulations on smaller municipalities.

The first phase regulated the following categories of discharges (Dodson, 1999):

- Discharges associated with industrial activities. This includes construction activities over 5 acres and hundreds of thousands of facilities.

- Discharges from large and medium municipal separate stormwater sewer systems. This essentially includes every drop of water that drains from these municipalities. Medium systems serve from 100,000 to 250,000 people and large systems serve over 250,000 people.

- Discharges which the director of the NPDES program designates as contributing to a violation of a water quality standard or as a significant contributor of pollutants to the waters of the United States.

2.3 NPDES Phase II

The second phase, published in the Federal Register on December 8, 1999, expanded the coverage of the NPDES permitting requirement. The new rule now includes small municipal separate storm sewer systems (MS4s) serving fewer than 100,000 people located in urbanized areas and construction activities from 1 to 5 acres. It also covers similar systems operated by federal government entities, such as military installations, large hospitals, prison complexes, and highways. The new ruling additionally encourages the use of existing programs and allows waivers and phase-in options for the systems serving less than 10,000 people.

The second phase requires MS4 managers to develop and implement stormwater management programs that incorporate minimum best management practices. In a recently released statement, the EPA listed six areas where dischargers must implement BMPs (EPA, 2000):

- Public education and outreach;
- Public involvement and participation;

- Illicit discharge detection and elimination;
- Construction site stormwater runoff control;
- Post-construction stormwater management; and
- Pollution prevention, or "good housekeeping," for municipal operations.

The EPA developed an especially useful website for understanding NPDES phase II requirements, www.epa.gov/owm/sw/phase2/index.htm.

2.4 Current Federal Permitting Requirements

To accomplish the goals of the Clean Water Act, the EPA considers all discharges into the nation's waters unlawful, unless specifically authorized by a permit. The issuance of permits is the Act's primary means of control, and a principal concern for any public works official dealing with stormwater. The law contains civil, criminal, and administrative enforcement provisions and also allows citizen law suits.

Any facility or municipality falling under Phase I or Phase II requirements that discharges stormwater in to the nation's surface waters, must seek coverage under either an individual or general permit. The EPA intends for most small MS4s to receive general permits. Each regulating agency writes the requirements and steps for inclusion under a general permit. To be covered under a general permit, an organization must submit a notice of intent that must contain the following minimum requirements: the best management practices it will implement to meet each of the six minimum measures; a measurable goal for each measure; and dates for starting and ending each measure.

For individual permits, organizations submit all the information required for notices of intents as well as the square miles served, maps showing pertinent information, a listing of all applied for and received construction permits, and other information requested by the regulating agency authorizing an NPDES permit. The authorizing agency then establishes

requirements in the form of pollution limitations and, as needed, technology based controls. The final permit specifies the minimum level of control technology applicable to each pollutant, the effluent limitations for pollutant levels that a discharger must meet, and the deadline for compliance.

Regulating agencies consider several issues when determining numerical effluent limitations. Limitations for all dischargers initially focus on regulating the discharge of bacteria, oxygen consuming materials and other conventional pollutants. The more stringent limits primarily address industrial concerns, namely toxic pollutants such as heavy metals, pesticides and other organic chemicals. The EPA has issued further guidance to states regarding limitations to maintain water quality standards for almost 120 other pollutants, mainly toxic chemicals (Dodson, 1999). The final limitation may be based upon an industry standard set by the EPA for the pollutant, or the need to maintain minimum quality standards in the receiving waters, whichever is stricter.

The limitations based on the receiving water's quality apply to surface waters already considered impaired even after point source polluters have installed the minimum required levels of pollution control technology. For these waters, a total maximum daily load (TMDL) is established for each pollutant. TMDLs set the maximum amount of pollution a body of water can receive and allocate this amount among pollutant sources. These limitations necessitate higher treatment requirements than for traditional industry standards.

The NPDES permit also may require dischargers to attain technology-based effluent controls. Two technology-based requirements appropriate for existing stormwater discharges are best conventional technology (BCT) and best available technology (BAT) (Sullivan, 1999). BCTs are applicable to conventional pollutants from industrial and municipal

discharges. BAT standards apply to industrial dischargers of toxic pollutants and refer to the best technology that is economically achievable.

Stormwater dischargers must also maintain records and carry out effluent monitoring activities as specified in their permit. Permits are issued for up to 5-year periods and must be renewed thereafter to allow continued discharge. The EPA encourages permitees to submit for initial permits and permit renewals a minimum of 180 days in advance before the date needed.

The NPDES permit, containing effluent limitations on what a source may discharge, is the Act's principal enforcement tool. The EPA may issue a compliance order or bring a civil suit in the U.S. district courts against persons or organizations that violate the terms of an NPDES permit. The penalty for such a violation can reach $25,000 per day. The Act authorizes stiffer penalties for criminal violations of the Act with negligent or knowing violations resulting in up to $50,000 per day, 3 years imprisonment, or both. A fine of as much as $250,000, 15 years in prison, or both, is authorized for 'knowing endangerment' violations that knowingly place another person in imminent danger of death or serious bodily injury. Finally, the EPA is authorized to assess civil penalties administratively for certain, well-documented violations of the law (Sullivan, 1999).

2.5 State Requirements

The Clean Water Act, as with most environmental laws, prescribes to a federal-state partnership where the federal government sets the agenda and delegates to the states certain responsibilities, including the day-to-day implementation and enforcement. Specifically, the Act delegates to qualified states the authority to issue discharge permits to industries, municipalities and other facilities and to enforce permits. Currently 43 states have qualified

to issue permits. The EPA regional agencies are responsible for issuing discharge permits in the remaining states. However, the EPA retains oversight of state enforcement. The EPA can take action if a state or local agency requests its assistance or whenever it believes that a state has failed to take timely and appropriate action.

Since the EPA has delegated stormwater regulation to the state level, the specific program requirements naval facilities are subject to differ from state to state. State requirements do not have to mirror Federal guidelines, but they cannot be more lenient (Sullivan, 1999). Presenting the varying requirements is well beyond the scope of an overview. As this report only covers the highlights of regulatory requirements, Public Works Officers should contact their local regulatory agency for details. Table 1 provides a listing of the various state stormwater regulatory agencies and their web site addresses as of the date of this report. The EPA also provides a web page for state and regional points of contact at www.epa.gov/ow/region.html.

3.0 BEST MANAGEMENT PRACTICES

This section discusses best management practices (BMPs) to control or prevent contamination of surface waters by stormwater runoff. BMPs are techniques that do not depend on mechanical treatment to improve the quality of stormwater runoff. Two distinct types of stormwater best management practices exist, namely preventive measures and control measures. (NCSUWQG, 1999) Preventive measures consist of largely nonstructural practices that attempt to eliminate runoff contamination, whereas, control measures involve structural methods to remediate contaminated stormwater. A further explanation of these two types of management processes follows.

3.1 Preventive Measures

Preventive measures are management techniques that attempt to reduce the exposure of stormwater to any materials that might contain pollutants. They are an extremely cost effective way to mange stormwater contamination problems (EPA, 1993). Organizations can often implement these techniques with little funding, no construction and minimal effort.

The first line of defense is incorporation of environmental concerns when developing land use planning, zoning and development restrictions. Design related practices focus upon redesigning structures to decrease stormwater accumulation, to reduce stormwater exposure to contaminants and to minimize surface areas of impervious materials to lower the volume of runoff. Preventive measures also include educating all levels of the public works organization, modifying maintenance procedures, and improving housekeeping practices used by facilities. Preventive measures can be divided in to two categories, source reduction practices and land use management practices.

3.1.1 Source Reduction Practices

Source reduction practices are frequently the least expensive ways to control stormwater pollutions (EPA, 1993). They focus on pollution prevention by stopping stormwater's exposure to contaminants at the source. After all, it is usually much cheaper and more effective to prevent stormwater contamination than to remove pollutants after the fact. The city of Seattle has developed a web page listing several source reduction best management practices at www.ci.seattle.wa.us/util/rescons/swq/bmp/default.htm. The following are several source reduction techniques:

Curb Elimination: Curbs have been found to increase pollution entering surface waters. Runoff flows at high velocities through the channels that curbs make, picking up pollutants

and sediment. Without curbs, stormwater runoff is free to spread out over existing vegetated areas. This reduces the velocity to allow pollutants and sediments to settle where they can be absorbed by the soil and used as nutrients by plants. Locations with existing curbs can remove the curbs or install curb outlets at appropriate places to allow the release of stormwater flow. Careful positioning of curb outlets and maintaining a street cleaning program help avoid flooding, erosion and trash buildup problems (NCSUWQG, 1999).

Animal Waste Collection: Animal wastes act as a source of organic matter and bacteria for stormwater runoff (NCSUWQG, 1999). The wastes can come from housing residents' pets, facilities that house animals and practices of spreading animal wastes on fields. This becomes particularly problematic when the wastes are directly deposited in gutters or washed into the stormwater collection infrastructure. Regulations that require collection and removal of wastes from public areas and areas exposed to runoff can greatly reduce the animal waste hazard. The regulations should also address proper disposal methods.

Education Programs: Proper education programs form the backbone of any source reduction practice. Most people will use new methods and materials once they understand the impact on their community's surface waters (NCSUWQG, 1999). This would help eliminate the large amount of pollutants entering stormwater merely from carelessness and ignorance. At the industry level, facilities managers can teach employees proper handling, storage, and disposal of hazardous materials and waste. Employee education programs include informal training, classroom lectures and self paced videos. At the public level, local governments can educate citizens through the use of existing mailings, such as utility bills, local media and town meetings. Essentially, educational programs should be implemented for everybody.

Exposure Reduction: One of the basic options for source reduction is to reduce the exposure of potentially pollutant causing materials to rainfall. The North Carolina State University Water Quality Group presents several straightforward techniques summarized below (NCSUWQG, 1999).

- MOVE OR REMOVE. Industries, municipalities and homeowners can eliminate pollution by simply moving materials indoors or removing materials, products, devices and outdoor manufacturing activities that contribute to stormwater pollution when exposed to the weather. Particularly, use or removal of rarely used materials stored outdoors simply and effectively remove pollutants.

- INVENTORY. An inventory of the items on commercial and industrial sites that are exposed to rain may provide useful information and a starting point for exposure-reduction activities. Examples are raw material stockpiles, stored finished products, and machinery or engines that leak fuel and oil.

- COVERING. The partial or total physical enclosure of stockpiled or stored material, loading/unloading areas, or processing operations. This BMP is applicable to industrial, commercial, and residential source elements such as storage areas for dry chemicals, and surface impoundments used for waste storage and disposal.

- EXPOSURE MINIMIZATION. Implementing "Just-In-Time" (JIT) management of materials and finished products to minimize the amount of materials in the stockyard and at the loading dock. JIT management uses very precise scheduling and intensive management to keep the amount of raw or finished products to a minimum, reducing waste, storage costs and clutter. It is intended to reduce overhead and make the workplace more efficient; however, it can also reduce stormwater pollution by reducing exposure of materials to rain.

- MAINTENANCE. Site cleaning to reduce the amount of pollutants available to enter stormwater. Recycling of empty drums and removal of hazardous substances and wastes as soon as possible. Grading and seeding of old stockpile areas and bare areas to reduce erosion and improve appearance. Preventive maintenance to reduce leaks, breakdowns, spills and accidents. Maintaining all pollution control devices in good working order.

- GOOD HOUSEKEEPING. Cleaning and trash pick up of grounds, parking lot and road sweeping, and disposal of old or unused equipment.

- PREVENTION PROGRAMS. Spill prevention and response programs and training to prepare employees to implement these programs.

Landscaping and Lawn Maintenance Controls: A significant amount of the pesticides and fertilizers used in lawn care and landscaping end up as pollutants carried to surface waters by stormwater runoff (NCSUWQG, 1999). Both housing residents and professionals contribute to the problem by not knowing the proper amounts of fertilizer and pesticides to apply, or by over applying. This is of particular concern when these methods are used in close proximity to bodies of water or with widely maintained areas such as golf courses and cemeteries. Possible controls include the use of hardy perennial plant species that require less water and fertilizer, homeowner education on fertilizer and pesticide usage, and stricter guidance for landscape maintenance professionals.

Pollutant Minimization: An important way to limit stormwater exposure to pollutants is to start with less of the pollutant. Techniques such as removing pollutants from the watershed, using alternative chemicals, using alternative practices, recycling, or reducing polluting chemical and material usage can produce significant reductions in stormwater pollution. The NCSUWQG provides several examples of pollutant minimization summarized below (NCSUWQG, 1999).

- COLLECTION/RECYCLING. Community hazardous waste and waste oil recycling centers. These activities remove some of the most polluting substances from places where the substances can enter stormwater runoff.
- SEPARATION. Connecting the drains from vehicle washing areas to the municipal sewer or sanitary sewer system to prevent discharge of the wash water into a nearby stream, if permitted by the local government.
- SUBSTITUTION. Using non-toxic or non-hazardous materials in place of hazardous materials, such as water-based degreasers and water-based inks, to reduce the amount of solvents and chemicals that enter the environment.

Parking Lot and Street Cleaning: Runoff from streets and parking lots is a primary source of pollutants in urban stormwater outflows (Ferguson, 1998). Although primarily performed

for aesthetic reasons, street cleaning improves water quality by physically removing potential contaminants. It further works to reduce clogging in storm sewer intakes, outlets, and in detention structures and ponds. Implementation plans can include requirements to regularly clean roadways and parking areas and for educating housing residents of the reasons not to use gutters to dispose of yard wastes. However, special consideration must be given to the material accumulated from street cleanings due to the heavy metals and other wastes from automobile traffic. This may require special disposal procedures or the use of creative reutilization alternatives.

Road Salt Application Control: Road salt is a common source of runoff pollutants (NCSUWQG, 1999). The first risk occurs with road salt storage. Properly constructing or modifying existing facilities can prevent stored salt exposure to rainfall. The second concern is the applied salt, which can be reduced by the use of sand or other material that is friendlier to vegetation and aquatic life.

3.1.2 Land Use Management Practices

Land use management practices attempt to reduce pollution by controlling usage of land in watersheds (NCSUWQG, 1999). Controls are often included during the project design phase and on revising existing site plans for retrofitting. They frequently require minimal, if any, maintenance and are very low cost.

Buffers, Easements and Setbacks: Buffer zone, easement and setback restrictions are typically established and managed by some arm of local government such as the public works planning division, the zoning commission, planning board, or soil and water conservation board. They are most effective when used in conjunction with other best management practices, namely those that act to help streambeds resist erosion, those that slow down runoff

and those that diffuse runoff. Controls can be in the form of base instructions, local ordinances or statewide matching funds programs. These methods are applicable for both new and developed areas.

Buffer zones are strips of vegetation, either planted or natural, around surface waters. These zones trap sediment and sediment bound pollutants, facilitate infiltration, and spread the runoff to help reduce the impact of stormwater runoff. Many locations have already established these programs to protect drinking water supplies, wells and wetlands areas (Dodson, 1999).

Setbacks work to protect surface waters through zoning and other regulations that prohibit development activities within a specified distance of a stream bank or other surface water. The use of setbacks also helps minimize erosion and the formation of gullies. They further facilitate the sedimentation of stormwater pollutants prior to their entering the water resource (Dodson, 1999).

Although not usually associated with protecting water resources, easements provide an alternative method for local civilian governments to establish control of strategic land (Dodson, 1999). Easement purchases from landowners can be solely for the development rights, for the entire property or for some other form that limits development. Establishing greenbelts around waterways through easements protects the waters and also improves neighboring property values by providing land for parks and recreational areas.

3.2 Control Measures

There are numerous structural best management practices for treating stormwater runoff prior to releasing it into surface waters (Urbonas, 1993). Their usefulness varies according to the quantity of runoff, nature of contaminants and various site specific

conditions. The most common techniques include water quality inlets, vortex solids separators, sand filtration, constructed wetlands, vegetative practices, infiltration devices, dry detention devices, and porous pavement. Numerous variations and combinations exist in commercially available systems that also warrant consideration when evaluating site-specific solution options.

To properly examine any treatment method, it is important to understand what pollutants are targeted for treatment. A significant number of different pollutants can be found in urban runoff. Table 2 lists the impacts to the environment caused by several common pollutants. To make runoff management programs workable, the EPA established a list of "...standard pollutants characterizing urban runoff" (Urbonas, 1993). They explained their selection as follows (Urbonas, 1993):

> The list includes pollutants of general interest, which are usually examined in both point and nonpoint source studies and includes representatives of important categories of pollutants – namely solids, oxygen consuming constituents, nutrients, and heavy medals.

The following constituents are included in the list (Urbonas, 1993):

TSS	Total suspended solids
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TP	Total phosphorus (as P)
SP	Soluble phosphorus (as P)
TKN	Total Kjeldahl nitrogen (as N)
$NO_{2\&3}$	Nitrite and nitrate (as N)
Cu	Total copper
Pb	Total lead
Zn	Total zinc

Each of the discussed practices mitigates some or all of these pollutants. Table 3 shows the effectiveness of the different BMPs at mitigating the various pollutants. The EPA has

developed several fact sheets for structural BMPs available over the world wide web at www.epa.gov/owmitnet/mtbfact.htm.

3.2.1 Water Quality Inlets

Water quality inlets (WQIs) are designed to remove pollutants from the first flush of stormwater runoff (Botts, 1996). The first flush of runoff contains the highest level of pollutants. WQIs typically consist of a sediment chamber, an oil separation chamber and a discharge chamber. They also may be referred to as oil/grit separators or oil/water separators. Figure 1 shows an example of a typical WQI.

Stormwater first enters the sedimentation chamber, where coarse materials settle. Water flows from the sedimentation chamber to the second chamber through an orifice, covered with a trash rack to remove larger debris. This second chamber functions as an oil/water separator. The third chamber discharges water through the outlet pipe. All chambers should maintain permanent pools to reduce sediment resuspension and manholes to provide access for cleaning and inspections.

Design Considerations. The primary design considerations are sizing of inflow and outflow piping and sizing the functional chambers based on a design storm event. They may be constructed on site, precast or manufactured by a vendor.

Advantages. Water quality inlets are useful for separating sediments and oils from stormwater runoff, improving downstream stormwater quality. They require only minimal space making them ideal for locations with limited area. WQI's relatively low cost to construct, typically $5,200 to $16,700, makes them attractive for small scale operations. (USDOD, 1997)

Disadvantages. WQIs are limited in their ability to manage large volumes of stormwater because high flows may result in resuspension of settled material. Also, they remove only minimal amounts of nutrients, metals, dissolved oils and organic pollutants other than free petroleum products. If not properly maintained, their ability to remove pollutants is further limited. Finally, disposal of solid and liquid residuals may require special permits.

Maintenance. Necessary maintenance includes keeping the inflow and outflow cleared and the removal of any accumulated sediments and oils. Required maintenance frequency varies from site to site. Minimum maintenance scheduling should include cleaning before the start of each major storm season and inspection after each significant storm event.

3.2.2 Vortex Solids Separators

Vortex solids separators are designed to physically remove solids and floatables from stormwater runoff (USDOD, 1997). Vortex units are cylindrical in design so that, as flow enters the unit tangentially, it induces a swirling vortex that concentrates solids at the bottom of the unit in the underflow. Clarified effluent exits from the top of the unit and returns to the receiving water. The solids can be removed from the bottom of the unit and sent to a holding tank/pond where further sedimentation occurs. Figure 2 presents an example of a sand separator unit.

Design Considerations. Vortex solids separator design should be based on planned quantity and types of pollutants to be removed as well as the pollutant's settleability characteristics (USDOD, 1997). Performance for each unit varies according to the manufacturer's actual vortex separation mechanism. The EPA provides design criteria for some common units, based on settleability studies (USDOD, 1997). Design specifications and pilot-scale treatability studies are necessary for each planned site.

Advantages. Vortex units are efficient at removing gritty materials, heavy particulates and floatables in low flow environments. They are relatively compact and useful where space is limited and where land constraints, such as steep slopes or unsuitable soil composition, prevent the use of other methods. They have no moving parts and therefore require only minimal routine maintenance.

Disadvantages. A major disadvantage is the vortex solids separator's limited effectiveness in wet-weather flows. Also, they may not meet water quality treatment standards for some locations. Essentially, they have minimal effect for treating pollutants other than solids.

Maintenance. Vortex solids separators require minimal maintenance. This is limited to routine inspections to verify inflow and outflow pipes remain clear, check for corrosion, and remove any residuals or accumulated solids if the unit lacks a foul sewer line.

3.2.3 Sand Filtration

Sand filters provide means to control both the quality and quantity of stormwater. They are composed of at least two components, a sedimentation chamber and a filtration chamber. The sedimentation chamber removes floatables and heavy sediments. The filtration chamber removes additional pollutants by filtering the stormwater through a sand bed. Sand filtration systems effectively remove suspended solids, biochemical oxygen demand, and fecal coliform bacteria (USDOD, 1997).

Design Considerations. The primary design considerations are the drainage area, anticipated runoff volumes and anticipated pollutants. There are several different sand filter designs, including the surface sand filter basin, the underground vault sand filter, the double trench sand filter, the stone reservoir trench sand filter and the peat sand filter system. Figure 3 is an example of a typical Washington , D.C. design underground vault filtration unit. Each design

has it's own advantages and disadvantages that must be evaluated in accordance with treatment goals. Web sites listed at the end of this section provide more detailed information on each design.

Advantages. Sand filters achieve high removal efficiencies for suspended solids, hydrocarbons, nutrients, BOD and fecal coliform bacteria (Botts, 1997). They provide some storage capacity to control stormwater flows. The impermeability of some basin designs limits the potential for groundwater contamination while treating stormwater. Also, the design is very flexible to accommodate drainage area served, filter surface areas, land requirements and quantity of runoff treated.

Disadvantages. A primary disadvantage is sand filtration's inability to remove dissolved pollutants and some forms of nutrients (USDOD, 1997). They also require periodic cleaning or replacement of the filter bed.

Maintenance. Sand filtration systems provide sustained performance with frequent inspections (USDOD, 1997). Accumulated trash and debris should be removed every 6 months. Every 3 to 5 years, depending on pollutant load, the filter fabric and media should be replaced. Testing of the media determines treatment and disposal requirements.

3.2.4 Constructed Wetlands

Since constructed wetlands are one of the more complex best management practices, they will be covered in slightly more detail. Wetlands are capable of removing many different types of pollutants from wastewater outflows through various natural physical, chemical and biological processes (Shutes, 1997). They can act as a storage area during periods of excessive runoff. They are relatively low maintenance operations. And, they have a generally positive image in the media and with the public.

Design Considerations. The final design for a constructed wetlands should include both engineering considerations and practical considerations (Urbonas, 1993). Engineering considerations primarily consist of the amount of water to be treated and treatment goals. However, practical considerations, such as the amount and shape of land available, may ultimately determine the nature of the final product.

The actual effectiveness of wetlands in removing the contaminants listed by the EPA varies from site to site in the United States. Several studies have evaluated the efficiency of individual constructed wetlands throughout the United States at treating wastewater. Urbonas (1993) summarized the findings of these reports. These studies indicate that properly designed wetlands are very effective at removing suspended solids and heavy metals. However, the ability of wetlands to remove nutrients from stormwater has produced much less clear results, showing wider variation between sites. Urbonas (1993) cites sources that found removal rates for organic Nitrogen that ranged between –4% and 62% and for total phosphorous that ranged between –4% and 90%. Schueler (1992), on the other handed, noted more clearly positive results with total phosphorus removal rates of 30% to 90% and soluble nutrient removal rates of 40% to 80%. This inconsistency highlights the need to perform a thorough evaluation of each site prior to constructing a full-scale treatment system.

Wetlands basins range from small basins suitable for treating runoff from a typical neighborhood to large basins designed for entire watersheds. The wetlands' final shape should maximize the runoff's contact time with the wetlands basin to optimize treatment. An understanding of design considerations for larger wetlands basins can be applied to the smaller scale basins and is presented in this section. Figure 4 presents an example of a typical wetlands basin and its primary components.

The inflow area, called the forebay, is designed to slow the water's flow to allow the largest sediment particles to settle out before the flow passes over areas with heavy vegetation. Forebays not separated from the wetland may include baffles to break up the inflow jet and to help spread stormwater uniformly over the entire area of the wetlands. The uniform spreading helps to maximize stormwater contact time with the wetlands' surface. Regular cleaning of the forebay greatly increases the period between dredging the wetlands.

Although relatively shallow, designing the wetlands' depth incorporates many factors (Urbonas, 1993). The bottoms of the wetlands should have variable depths to promote diversity in the ecological system and therefore in the biological and physical treatment processes. The wetland must also maintain minimum depths during dry weather to sustain itself. Wetlands that are too shallow become a nuisance in dry periods, becoming breeding grounds for mosquitoes and developing a boggy, unsightly appearance. Variable depths over 18 inches deep provide areas deep enough to breed the mosquito predatory fish that control the mosquito population. The primary concern in wet weather surcharge depths is to protect the plants from long-term inundation and possible damage. The majority of species of wetlands vegetation can survive short periods of inundation. Therefore, maximum surcharge depth should ensure that a large percentage of the plants survive.

The last section of basin design is the outflow area. The deeper water at the outlet helps prevent the growth of plants that might clog outlet pipes (Urbonas, 1993). The use of large riprap in the outlet area further inhibits plant growth. This is especially critical when the outlet serves a small watershed area that requires smaller outlets to ensure minimum residence time. However, no matter the design, regular maintenance is necessary to completely prevent outflow blockages.

Advantages. Wetlands are popular with the public as additional green space provides a sense of taking care of the environment. They remove most of the pollutants typically found in stormwater runoff. They provide excess storage capability to help prevent down stream flooding. Depending upon design, they can act to recharge groundwater.

Disadvantages. Actual levels of treatment for a specific pollutant are unknown and cannot be precisely determined without a pilot study (Urbonas, 1993). Wetlands require large areas for construction and to allow access for maintenance. If not properly maintained, they may become an eyesore and nuisance.

Maintenance. After initial construction the constructed wetlands require regular inspections to monitor hydrologic conditions and ensure vegetative establishment (Urbonas, 1993). This incorporates frequent harvestings to remove unwanted or overly opportunistic plant species. Long-term maintenance consists of periodic removal of accumulated sediments, trash and other debris, and landscape management. Additional maintenance concerns include nuisance insects, odors and algae.

Alternatives. Since different types of wetlands vegetation have varying effectiveness with different pollutants, environmental professionals have developed several alternatives. One alternative is using a meadow wetlands that primarily consists of meadow-type wetland grasses. They are dryer with mostly subsurface flow, only occasionally having standing water. Another form of wetlands is the boggy type that consists of reed-type emergent vegetation and has practically no permanent pool. Both of these types are prone to breeding mosquitoes, a fact to consider for urban areas. Also, a detention basin to remove most of the sediment and equalize flow should precede both these types.

Wetlands channels are excellent options in urban areas with limited land availability. Wetlands channel designs differ from traditional channel designs in that they slow water flow rates to avoid scouring and they maintain some minimum water level necessary to sustain the wetlands' vegetation. Similar to wetlands basins, they utilize natural processes to treat stormwater and remove pollutants.

They have the advantage over traditional storm sewers and concrete–lined channels of providing residual capacity for excess flow that decreases peak flows down stream. They frequently have a lower construction cost and enhance the quality of water. They also can provide a green belt that supports urban wildlife and recreation activities.

Disadvantages include the need for greater right-of-way, higher maintenance costs, possibly providing breeding grounds for mosquitoes, and the eventual requirement for dredging. These disadvantages can be minimized with careful land use planning and sound design. Also, the actual effectiveness of wetlands channels at removing various pollutants has not been quantified, but is anticipated due to wetlands effectiveness in other environments (Urbonas, 1993). Research is still needed to adequately evaluate the effectiveness of this treatment method.

3.2.5 Vegetative Practices

Vegetation reduces surface water pollution by reducing runoff velocity to facilitate particulate sedimentation and stormwater infiltration. Common methods include filter strips, grassed swales, buffer zones, riparian areas, and wetlands. These vegetative practices are frequently used as pretreatment for other BMP systems (NCSWUWQG, 1999). Other sections discuss buffer zones, riparian areas and wetlands. Therefore this section will focus on swales and filter strips.

Both swales and filter strips are relatively flat grassy areas that provide initial water treatment. They are gradually sloped and exploit the resulting velocity reduction to cause particulate sedimentation and infiltration of runoff. Actual removal rates are highly variable and depend upon the quantity of flow, types and quantities of vegetation, and soil characteristics. Grassed swales are grass covered earthen channels used primarily in single-family residential developments, at the outlets of road culverts, and as highway medians. Filter strips are bands of close-growing vegetation planted between pollutant source areas and receiving waters. They are typically 10 to 20 feet wide and planted with grass, but may also contain shrubs and woody plants. They are used primarily in residential areas around streams or ponds or as pretreatment devices for other stormwater control practices.

Design Considerations. Vegetative practices remove pollutants such as sediments, organic matter and trace metals by encouraging infiltration, facilitating sedimentation, and thereby increasing plant uptake (Dodson, 1999). Therefore, effective practices require flat areas large in relation to the drainage area and deep water tables. Swales should have as little slope as possible to maximize infiltration and reduce velocities. Filter strips work best with a 5% or less slope and become ineffective with slopes over 15%. Filter strips fail very easily if not maintained regularly. Further, to prevent erosion channel formation, a level spreader should be constructed along the top edge of the strip to disperse concentrated flows evenly. Grass height also impacts pollutant removal as taller grass will slow velocities more but shorter grass tends to take up more pollutants as nutrients.

Advantages. Vegetative practices are relatively inexpensive. They remove sediment, organic matter and trace elements (Dodson, 1999). In addition to treating stormwater, they reduce erosion and the resulting surface water pollution. These practices are simple to

construct, economical and effective. Grassed swales and filter strips also provide aesthetically pleasing green spaces.

Disadvantages. Vegetative practices remove only small amounts of pollutants. These practices have minimal impact on regulating peak flow or detaining runoff (Dodson, 1999). They also require frequent landscape maintenance.

Maintenance. Maintenance for both swales and filter strips basically involves normal landscaping activities such as mowing and reseeding as necessary. It also includes periodic inspections, controlled fertilizer application, trash and debris removal, and repair of eroded areas and bare spots (Dodson, 1999). Strips used for sediment removal may further require periodic regrading and reseeding of their upslope edge. Accumulated sediment must be removed because it can kill vegetation and interfere with uniform flow by changing the elevation of the edge.

3.2.6 Infiltration Devices

Infiltration devices remedy stormwater issues by facilitating the exfiltration of water into the soil (Dodson, 1999). This acts to remove pollutants from stormwater, to reduce runoff flows, and to recharge or replenish the ground water. Pollutant removal occurs through adsorption onto soil particles, and chemical and biological degradation within the soil. Properly designed, these devices can closely reproduce pre-development water balances. The ground water recharge capability is of significant importance in areas with a high percentage of impervious surfaces. Options to advance pollutant removal include increasing detention times to allow more time for sedimentation and planting vegetation on the basin bottom to increase settling, pollutant up take as nutrients, and pollutant adsorption. Common devices

include infiltration basins, infiltration trenches and dry wells. Figure 5 shows an example of an infiltration trench

Design Considerations. To function properly, infiltration devices require low water tables and permeable soils able to handle design flows (Dodson, 1999). Actual sizing and location of devices depends upon the method selected and the drainage basins. Smaller devices can be located under parking lots and roads or near buildings to minimize space requirements. Several smaller devices can replace a larger one to resolve location issues.

Advantages. Infiltration devices can have very high pollutant removal rates. Their variable size and low visibility, when installed underground, allow greater flexibility for the location of many devices on one site. They help replenish the ground water and reduce both stormwater peak flows and volume.

Disadvantages. Infiltration devices have a high failure rate (Dodson, 1999). They demand frequent cleanings to prevent sedimentation from clogging the soil. These devices only function in soil conditions permeable enough to remove design flows and with a water table at least 2 feet below the bottom of the device. They have limited usefulness when installed close to wells or areas subject to high pollution loads, such as gas stations.

Maintenance. Maintenance requirements include regular inspections, removal of trash and debris from inlets, and landscaping (Dodson, 1999). Sedimentation basins used to pre-treat stormwater need regular cleaning to prevent clogging of the soil matrix. Clogged soils often call for a complete rebuilding of the device.

3.2.7 Dry Detention Devices

Dry detention basins temporarily capture a portion of stormwater runoff that is later slowly released to reduce downstream flooding and remove a limited amount of pollutants

(Dodson, 1999). Common uses consist of reducing peak stormwater discharge, preventing downstream scouring and controlling flooding. They are referred to as "dry detention" because these devices are designed to dry out between rain events. Pollutant removal occurs through the sedimentation of solids and other particulates. This pollutant removal function is only a secondary benefit, sometimes with limited effectiveness.

The most common devices for dry detention are the dry detention basin and the extended dry detention basin. These structures retain an amount of water determined by design criteria from a storm and release the water through a controlled outlet over an extended period of time. The extended detention basin differs from the dry detention basin in that it drains more slowly and may maintain a permanent pool of water. Compared to other best management practices, dry detention basin prove low to moderately effective at pollutant removal.

Design Considerations. Major design considerations for dry detention basins take into account calculating appropriate detention times, treatment of the expected range of volumes of stormwater, and proper site location for basin construction (Dodson, 1999). The design typically incorporates retention for 24 hours to maximize sedimentation. Additional considerations include permeable soil and a water table at least 2 feet below the bottom of the basin to facilitate basin drainage between storm events. A common design modification is the addition of a forebay. A forebay is a concrete basin separate from the rest of the dry detention basin that pre-treats the runoff by capturing debris and sand deposits in an area easily cleaned.

Advantages. A significant amount of data exists on dry detention basins, facilitating design and maintenance considerations (Dodson, 1999). They are extremely flexible, allowing them to handle different sized watersheds and be easily incorporated in to site designs. They have

demonstrated a capability to remove certain types of pollutants from stormwaters. They are easily modified to meet both additional and decreasing flow requirements.

Disadvantages. Dry detention basins provide only limited protection to surface waters, as they are ineffective in removing most types of pollutants (Dodson, 1999). Further, pollutants that have settled out are subject to resuspension during subsequent storm events and being transported to the receiving waters. Dry detention basins display a tendency to retain permanent pools due to ineffectual maintenance of outflows and inadequate infiltration between closely spaced storm events. The resulting standing water presents an eyesore and nuisance, especially when combined with floating debris. Therefore, sites need concealment or landscape screening. They generally take up large areas, both for the actual device and to allow easy access for maintenance equipment, a significant issue in locations with high property values. Compared to other BMPs, they have high maintenance costs.

Maintenance. Maintenance concerns for dry detention basins focus on preventing clogging, standing water, and the growth of weeds and wetland plants. This requires frequent inspections, mowing and cleaning to unclog outlets. Normal annual maintenance costs can range from 3-5% of construction costs (Schueler, 1987). In addition, the basin requires extensive cleaning out every 10 to 20 years to remove accumulated sediment, mud, sand and other debris.

3.2.8 Porous Pavement

Porous pavement systems attempt to minimize surface runoff by reducing the imperviousness that occurs with installing traditional pavement (Urbonas, 1993). The systems typically consist of the surface pavement, the underlying aggregate, and the subgrade. Figure 6 presents a typical porous pavement cross section. To function correctly, these

systems need permeable soils and low water tables. In addition to reducing runoff quantities, porous pavement systems remove pollutants through adsorption, filtration and microbial decomposition. They have demonstrated high removal rates for sediments, nutrients, organic matter and trace metals (Schueler, 1992). These pavements do not have the strength of traditional pavements and therefore must have restrictions placed on their usage, typically limiting them to parking areas used by automobiles with few trucks.

Design Considerations. Porous pavement systems follow one of two basic designs (Urbonas, 1993). The first system consists of porous asphalt or concrete pavement, without the finer aggregate used in traditional design mixes, placed over a thick base of open-graded granular material. The second system consists of modular, interlocking open-cell concrete or masonry blocks installed over a base of open-graded coarse gravel. Both designs may include an additional reservoir of open-graded coarse aggregate to provide runoff storage prior to exfiltration. In addition, a geo-textile fabric is typically installed under the granular base to prevent migration of soils from the subgrade into the open-graded aggregate layers.

Advantages. Porous pavement systems have demonstrated capabilities to redirect large quantities of runoff to groundwater recharge and to treat pollutants found within the runoff (Schueler, 1992). Making use of existing paved areas, they may eliminate the need to construct other BMPs, saving valuable property and resources for other usages. They are particularly effective for infrequently used parking areas. They also may eliminate requirements for a separate stormwater conveyance system.

Disadvantages. One the main disadvantages of these systems is their limitation for traffic loadings. They also experience a high failure rate. Improper construction, accumulated sediment and oil, or resurfacing causes clogging and system failure (Schueler et al., 1992). Of

the two systems, the modular, interlocking, open-cell concrete block type tends to remain effective for considerably longer than porous asphalt or concrete pavement.

Maintenance. Porous pavement systems require routine maintenance to retain their effectiveness (Schueler, 1992). Maintenance should include quarterly vacuum sweeping and/or jet hosing to maintain porosity. Additionally, road maintenance efforts should avoid procedures that would clog the pavement, such as applying a seal coat.

3.3 Best Management Practice Selection

The first step in selecting best management practices is establishing pertinent existing site information. Barraud, et al, identifies several site specific criteria necessary for proper selection. Concerns about the soil include its behavior in the presence of water, bearing capacity, and soil permeability, both at the surface and below the surface. Regarding groundwater, criteria consist of the water table elevation and groundwater vulnerability to contamination. For the runoff, issues comprise quantity and arrival rate of flows, frequency of flow, risk of polluted waters, risk of silt bearing water, and other types of anticipated stormwater pollutants. Additional criteria include traffic type, existence and type of permanent outflow for runoff, site slope, and space availability.

In addition to the site criteria, other factors include monetary resources available, land usage in the area surrounding the future BMP, maintenance capabilities, and desired economic life. Selection tables provide a starting point for decision making. The world wide web contains several sources to aid in BMP selection. Two especially useful sites are www.txnpsbook.org/BMPs/urbmps-3.htm, which includes a BMP decision tree, and h2osparc.wq.ncsu.edu, which describes BMPs for different fields, provides information on several BMPs and presents data on various pollutants and design levels. The American

Society of Civil Engineers is also developing a database of BMPs and their effectiveness at www.asce.org/peta/tech/nsbd01.html.

4.0 STORMWATER INFRASTRUCTURE MAINTENANCE

The backbone of any Naval base's stormwater infrastructure is its storm drainage system and related components. Degradation and failure of this backbone is a primary source of concern not only at Naval installations, but also in urban stormwater management programs throughout the United States. Debo cites a survey of North Carolina cities indicating that they attribute 20% of their flooding problems to maintenance problems. Other authorities have found similar statistics and trends (Debo, 1995).

Modern storm sewer management practices identify several types of sewerage failure along with appropriate diagnosis techniques and rehabilitation options. Sewerage failure categories include structural, hydraulic and environmental (Delleur, 1994). Structural failures usually start with a minor initial defect that leads to further deterioration and eventual failure of the facility. Examples include subsidence, corrosion, collapse, and loss of soil support. Hydraulic failures occur when the drainage system fails to remove runoff within design conditions. Some common examples are flooding, surcharge, infiltration and water hammer. Environmental failures refer to those that violate any of several discharge regulations. Two examples include storm sewer overflow and discharging polluted runoff into receiving waters. Diagnosis for each involves various forms of monitoring, inspection and modeling and is the foundation for any management and maintenance program.

Maintenance programs are suited for addressing structural and hydraulic failures. Actual maintenance falls in to one of three categories: routine, remedial and capital improvements (ASCE, 1992). Maintenance procedures differ for each of the many

components of drainage systems. Routine maintenance covers activities occurring on a regular basis, such as removing debris from catchments. Remedial maintenance rectifies specific deficiencies, such as a corroded pipe, but does not impact the component's capacity. Capital improvements actually replace identified facilities, such as a pipe that is too small for current drainage flows, with larger or improved designs. This may be necessary if a well established maintenance program exists, yet hydraulic failures persist. Since civilian contracted engineering firms will design the majority of capital improvement projects, this report focuses on routine maintenance and rehabilitation.

4.1 Routine Maintenance

All public works management systems should contain an established program of routine stormwater infrastructure maintenance (ASCE, 1992). This requires a staff of personnel trained in stormwater maintenance issues. Effective programs consist of both scheduled and unscheduled maintenance. A well maintained system is necessary to adequately remove runoff from the next storm event.

Routine maintenance for all system components has similar criteria. The first step in any program is developing established inspection practices. Inspections should occur annually as a minimum and preferably semiannually and after every major storm event. Inspections may be performed manually or with any of numerous automated methods currently available. Debris and trash must be removed periodically to prevent clogging of trash racks, curb inlets, pipes and channels. Accumulated silt that impacts the design capacity of pipes and channels has to be removed. Access avenues, including manholes and trails, require regular maintenance to remain functional. Lastly, vegetation around inlets and along channels needs routine mowing to avoid obstructing stormwater flow.

4.2 Pipeline Rehabilitation

Pipeline rehabilitation is often a preferred option to replacement of failing components to minimize the impact on the community and for the cost savings provided (EPA, 1999). The cost savings from rehabilitation comes from several different aspects. Table 4 lists typical cost ranges for rehabilitating small sewer mains. The main source of savings is the avoidance of trenching and the related replacement of damaged surface structures, often the largest cost in sewer construction. All of these rehabilitation options decrease the amount of trenching and some eliminate the requirement entirely. In addition, trenchless rehabilitation methods cause less facility disturbance and environmental degradation than traditional replacement methods. Another potential source of savings is the reuse of the existing pipe, culvert or manhole as the primary structural component for the system.

There are several different alternative techniques available. Table 5 provides an overview of the different procedures used for piping, their applications and principle advantages and disadvantages. They include pipe bursting, sliplining, cured-in-place pipe, modified cross-section lining, spiral wound pipe, and coatings. These techniques are fairly well developed with numerous field applications. All necessitate proper preparation of the existing pipe prior to application. Pipe preparation may include removing roots, sedimentation and encrustation, cutting out intruding connections, and cleaning to an appropriate level.

4.2.1 Pipe Bursting/In-Line Expansion

Pipe bursting, or in-line expansion, is a technique where the existing pipe is forced to expand by a bursting tool (EPA, 1999). Companies have developed and patented numerous methods to perform in-line expansion, all of which use the existing pipe as a guide for an

expansion head. The expansion head, usually pulled by a cable and winch, pushes the pipe radially outward until the pipe cracks, making space for a new pipe. The bursting tool simultaneously drags the new pipe behind itself for installation. Figure 7 shows a typical pipe bursting system.

Bursting tools use either static or dynamic expansion heads to expand the existing pipe. Static heads have no internal moving parts and use the pulling action of the bursting tool to force the existing pipe open. Dynamic heads, on the other hand, apply hydraulic or pneumatic forces at the impact point. Pneumatic heads operate by pulsating air pressure within the bursting tool and hydraulic heads work by using hydraulic pressure to expand and contract the head. The tool then drags new pipe behind it to replace the broken existing pipe. Dynamic heads often prove necessary in difficult soils or with hardened pipe materials. However, the movement of the dynamic head against the surrounding soils can cause additional pressure and ground settlement. Therefore, installers typically use static heads whenever possible.

4.2.2 Sliplining

The sliplining process employs a liner of a smaller diameter than the deteriorated pipe to restore the pipeline. The liner is placed within the pipe and the area between the liner and the existing pipe is typically filled with grout to prevent leaks and provide structural integrity. If the lining is not grouted, then it cannot be considered a structural liner. (Institute of Civil Engineers, 1982) Grouting must be continuous since grouting only at manholes or access points may lead to structural failures or leaks.

There are three methods of sliplining installation, namely continuous, segmental and spiral wound (EPA, 1999). In continuous sliplining, the pipes are joined to form a continuous

segment. The segment is then inserted into the existing pipe from a manhole or access pit large enough to accept the bending of the pipe section. The segmented method requires assembly of the different segments at the access point. One advantage is that this method does not require rerouting of flow, actually using existing flow as a lubricant to aid in lining installation. During spiral wound sliplining, interlocking edges on the ends of the pipes connect different pipe segments. The pipe is then inserted in to the existing pipe.

Although, sliplining methods can often make use of existing manholes, most of the time they require an insertion pit as a proper access point. This makes sliplining not a totally trenchless operation. However, there is a considerable decrease in trenching requirements that results in significant cost reductions. Actual excavation requirements are dependent on different site conditions.

4.2.3 Cured-In-Place Pipe

The cured-in-place pipe process involves inserting a thermosetting resin coated flexible fabric liner into an existing pipe and curing it to form the new liner (Osborn, 1994). The liner is usually inserted into the pipe through an existing manhole. Installation processes include the winch-in-place and invert-in-place methods. With the winch-in-place method, a winch pulls the liner thru the pipe. The liner is then inflated to push it against the existing pipe where the resin makes contact. The more common method, invert-in-place method, uses air or water pressure to install the liner. The liner is secured at the beginning of the pipe, then the air or water pressure forces the liner through the pipe and turns it inside out. The pressure also pushes the resin-coated tube against the pipe wall. Figure 8 illustrates the invert-in-place process. After installation for both methods, heated water is circulated through the tube to cure the resin coating and to form a strong bond between the liner and the pipe.

When the liner expands to fit the existing pipe, it forms dimples at lateral locations. The use of TV inspection or robotic equipment locates the dimples in the line. Laterals are also sometimes marked with the placement of a protruding device to aid in their location. The laterals are then reinstated by using a remote cutting device, or, for large diameter pipes, manual cutting.

4.2.4 Modified Cross Section Lining

Another method available for smaller pipes, those up to 24 inches for most techniques and 46 inches for thin-walled lining, is the modified cross section lining method (Debo, 1995). This method uses various techniques to insert a Polyvinyl Chloride (PVC) or High Density Polyethylene lining into existing pipes. One technique is to modify the pipe's cross section through deformation. The pipe is typically folded into a "U" shape to be inserted into the pipe, as shown in Figure 9. The liner is then heated and pressurized to reform to its original shape. A second technique, the draw down process, uses chemicals and a series of dies to temporarily reduce the pipes diameter by 7 to 15%. After insertion, the liner cools and expands to its original diameter. A related technique, the roll down process, applies a series of rollers to reduce the liner's diameter. Once more, heat and pressure reform the liner to its original size. A final modified cross section technique inserts and secures a thin walled tube of slightly smaller diameter than the existing pipe.

The modified cross section methods do not rely on resins to form a tight seal, but rather the pressure from the expansion of the pipe. This also decreases down time, as curing time wait is eliminated. As with other methods, this method forms dimples at intersecting laterals that must be located. These laterals can be restored with either remote or manual cutting devices.

4.2.5 Spiral Wound Pipe

This method uses a winding machine to wind PVC strips into a tube (McAlpine, 1994). Depending on the design, the strips are either interlocking or use a second component to join strips together. The tube is then propelled down the existing pipe by the same winding machine, as illustrated in figure 10. The annulus between the liner and the existing pipe is a weak point of the system. Therefore, grouting of the annulus is necessary to provide structural integrity and bond the liner to the pipe. The grouting also seals the existing pipe and restores its structural integrity. "Recent tests at Utah State University demonstrated an increase in strength (load required to cause a measurable deflection) of 3-to-1". (McAlpine, 1994)

The liner is continuous throughout the length of the pipe and can be modified to any size up to 120 inches and any shape. As with other methods, the installation process seals off access to laterals that must be reinstated.

4.2.6 Coatings

Properly installed in-situ coatings increase the strength of existing pipe, protect existing surfaces from corrosion or abrasion, and improve the pipe's hydraulic performance. They are only suitable for sewers larger than 48 inches in diameter due to access requirements. (ASCE, 1994) They are also difficult to apply where significant infiltration already exists and may require control measures.

The most frequently used treatments consist of gunite, shotcrete and cast-in-place concrete (ASCE, 1994). Gunite and shotcrete are both installed through a hose at high velocity. Shotcrete refers to wet-mix processes and gunite refers to dry-mix processes. They usually incorporate steel or mesh for additional strength and to limit cracking. Also, various

latex polymers can improve bond strength, reduce adsorption and permeability, and increase chemical resistance. Cast-in-place concrete rehabilitation uses slip- or fixed-form construction practices for concrete placement. It may include reinforcing steel, mesh or hand placed cages for additional strength. This technique is effective for conduits of any shape or size. However, it requires thorough cleaning and dewatering prior to rehabilitation.

4.3 Manhole Rehabilitation

Manholes are a second major component of pipeline systems for storm sewers and are managed along with the storm sewer pipes. Manhole inspection and rehabilitation is typically easier than that for pipelines due to easier access and more working space. "Manholes are rehabilitated to correct structural deficiencies, to address maintenance concerns and eliminate inflow and infiltration. Manhole rehabilitation may also lessen or prevent corrosion of the internal surface caused by sulfuric acid formed when hydrogen sulfide gas is released from the wastewater to the sewer environment". (ASCE, 1994)

Numerous methods are available for consideration for manhole rehabilitation, and new products are constantly developed. The actual method selected should depend upon the types of problems, risk of damage or injury, structural characteristics, condition, age, and value in terms of rehabilitation performance. Structural degradation occurs in many forms, including vertical separation at any joint, degradation of the frame seal, displacement, and corrosion from hydrogen sulfides. Infiltration and inflow (I/I) into manholes from this degradation forms a considerable percentage of the total I/I in sewer systems. General maintenance needs form the final considerations, especially buried and inaccessible manholes, corroded steps, offset frames and other utilities passing through the manhole. The most frequently used

methods available to restore manholes are chemical grouting, coating systems, structural linings, and corrosion protection.

4.3.1 Chemical Grouting

This method primarily addresses reducing I/I in manhole structures, as it does not add to the manhole's structural integrity (ASCE, 1997). The method involves application of pressure grouts to joints and other areas showing signs of infiltration. This method requires excavation around the manhole, as the grout is applied to the manhole's exterior. Grouting works best for brick manholes with somewhat tight joints, active I/I, no structural defects, and cohesive soils with optimal moisture content. Depending on site conditions and rehabilitation requirements, the grout may be acrylamide, acrylate, urethane foam or urethane gel. The actual success will depend upon soil and groundwater conditions, injection patterns, gel time, grout mixture, containment of excessive grout migration and selection of the proper type of grout. (ASCE, 1997)

4.3.2 Coating Systems

Coating systems utilize cementitious materials containing Portland cement, finely graded mineral fillers and chemical additives. They are applied in one or more layers to the interior of the manhole either by machine or hand. The coating can be used to cover the entire manhole and even make repairs to the bench and inverts. They are ideally suited for brick structures with observed infiltration and inflow, missing or deteriorated mortar joints, and site conditions that prevent excavation. (Osborn, 1994)

Coating systems require proper surface preparation prior to installation to ensure successful chemical and mechanical bonding. Surfaces should be prepared with high-pressure water blasting to etch bricks and remove defective mortar. All voids should be packed and

treated with patching compounds. Coating systems are limited to manholes showing little movement as they have minimal intrinsic structural quality. They also require treatment with a surface coating where hydrogen sulfides exist.

4.3.3 Structural Lining

Structural linings include several methods that totally restore the structural integrity of a manhole (ASCE, 1997). They are high cost when compared to coating systems and chemical grouting. Therefore, requirements other than reducing and controlling I/I, such as severe structural degradation in an area that prohibits excavation, should exist. Typical requirements consist of walls with a minimum diameter of 48 inches, substantial structural degradation, accessible location, substantial project size and life cycle cost justification.

The design of the lining involves engineering considerations, incorporating an ability to withstand external groundwater pressure, vertical traffic and ground loadings, maintaining a finished inside diameter of 36 inches, and a minimum 3-inch wall thickness. Methods include cast-in-place concrete, prefabricated reinforced plastic mortar, prefabricated fiberglass reinforced plastic, spiral wound and cured in place liners.

4.4 Open Channel Rehabilitation

Rehabilitation options for open channels are similar to the original construction techniques. Failures requiring rehabilitation include undermining of any structural component, significant erosion forming a second channel, degradation at tributary outlets or around energy dissipation basins, and deformation of the channel banks from scouring, loss of riprap, settling or spot erosion. Prompt repair of identified problems will return a facility to service with little threat of further damage or failure.

Rehabilitation for earthen slopes, bottoms and access routes may involve the addition of fill, regrading and reseeding to prevent future erosion and damage. Damaged, but structurally sound, concrete components may require coating with shotcrete or gunite. Undermined or structurally damaged components usually require replacement with either precast or cast in place new components.

5.0 CONCLUSIONS

In today's environment, attempting to understand all necessary stormwater related topics is a complicated undertaking. The extensiveness of current requirements increases the amount of management oversight necessary for typical public works stormwater related concerns. Naval Officers often assigned to these stormwater related positions, either from in house reassignments or permanent change of station orders, typically have a limited stormwater background.

Newly assigned Officers are faced with a significant amount of written material they must review just for a basic understanding of key issues. This report is an attempt to ease the burden on these Officers. Its overview of many important topics tries to provide a basic understanding of the issues involved. It is arranged in a format to simplify referencing new concerns as they arise. It also provides sources for additional information and for information specific to different locations.

A final general comment on the material provided. I avoided providing my opinions on the feasibility of the different options discussed. I merely attempted to present the topics from the research I accumulated. It is up to the individual Public Works Officer to determine the applicability of different options to their situation.

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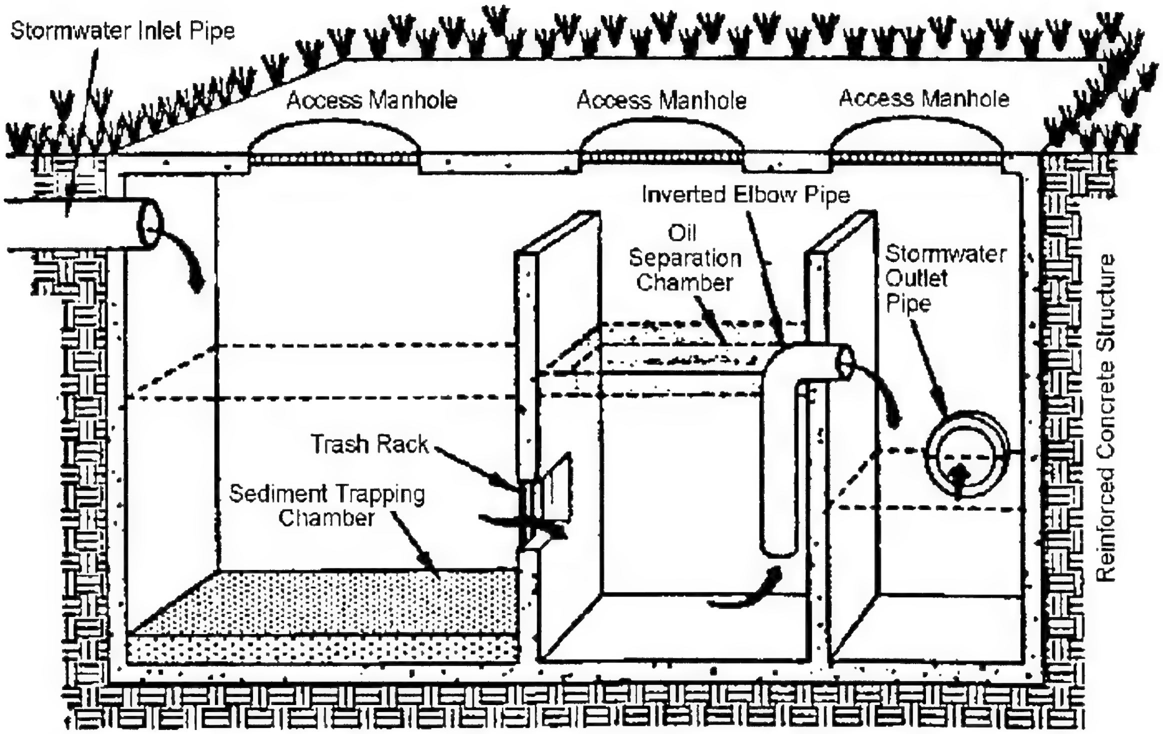
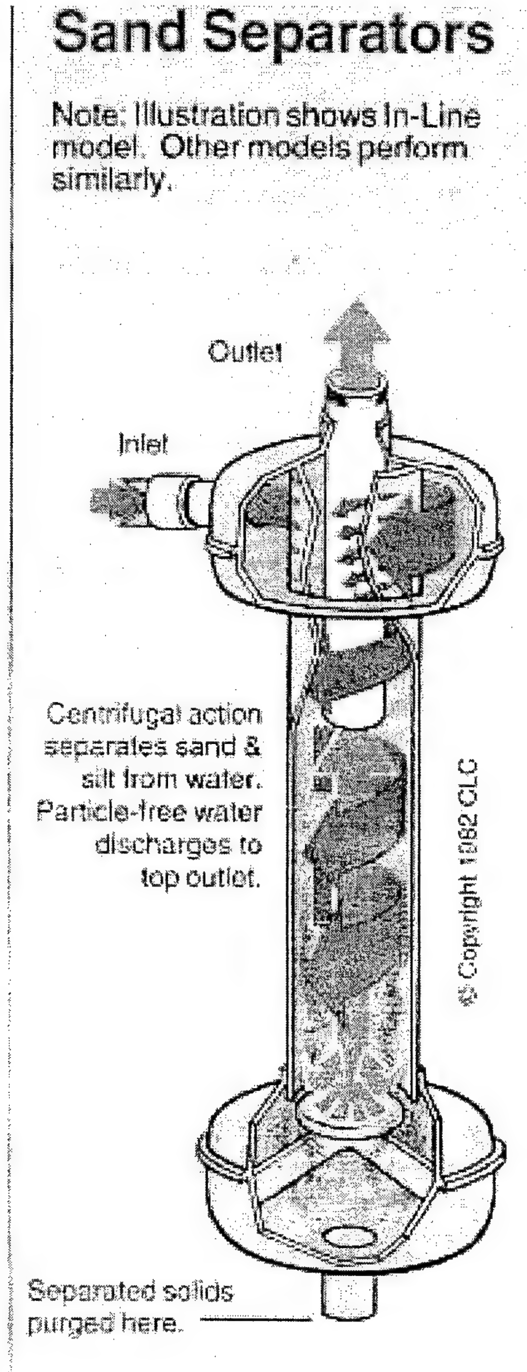


Figure 1: Water Quality Inlet (Botts, 1996)



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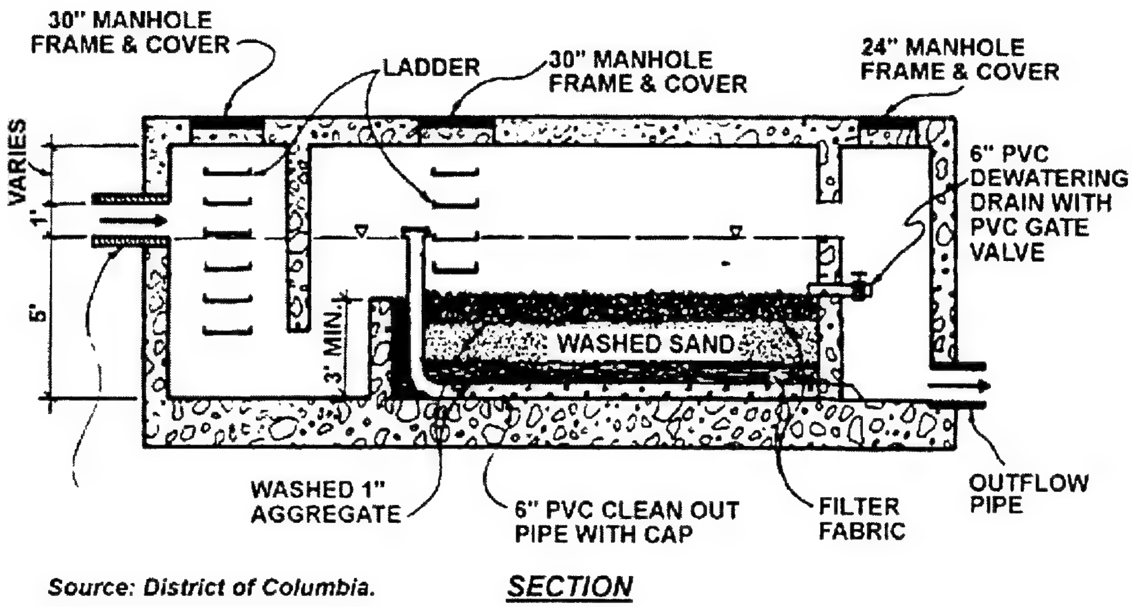


Figure 3: Sand Filtration (Botts, 1996)

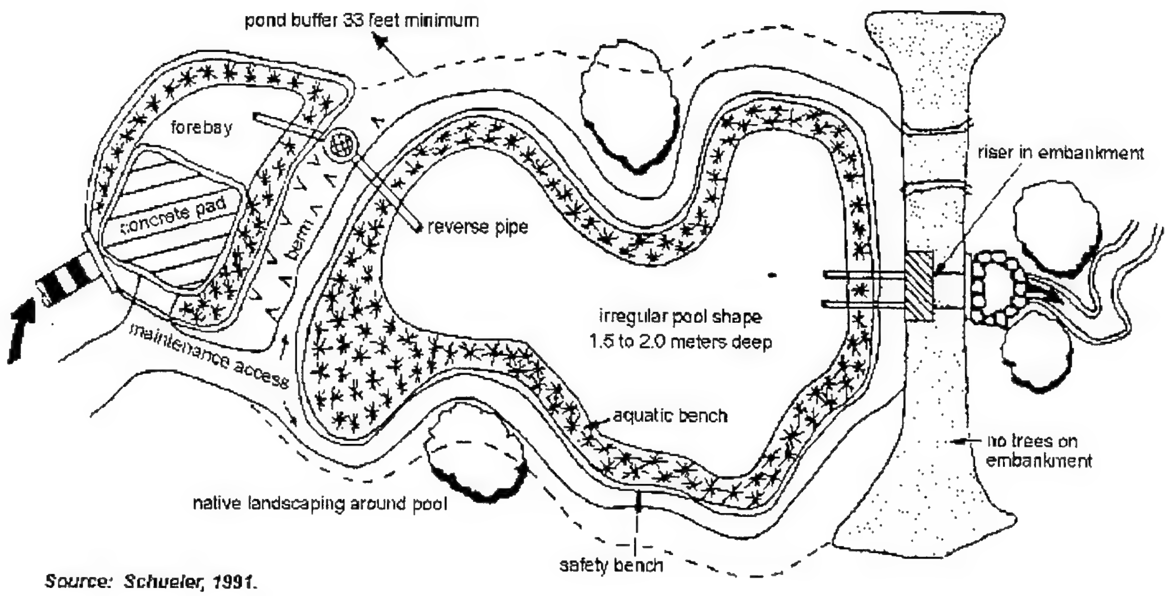
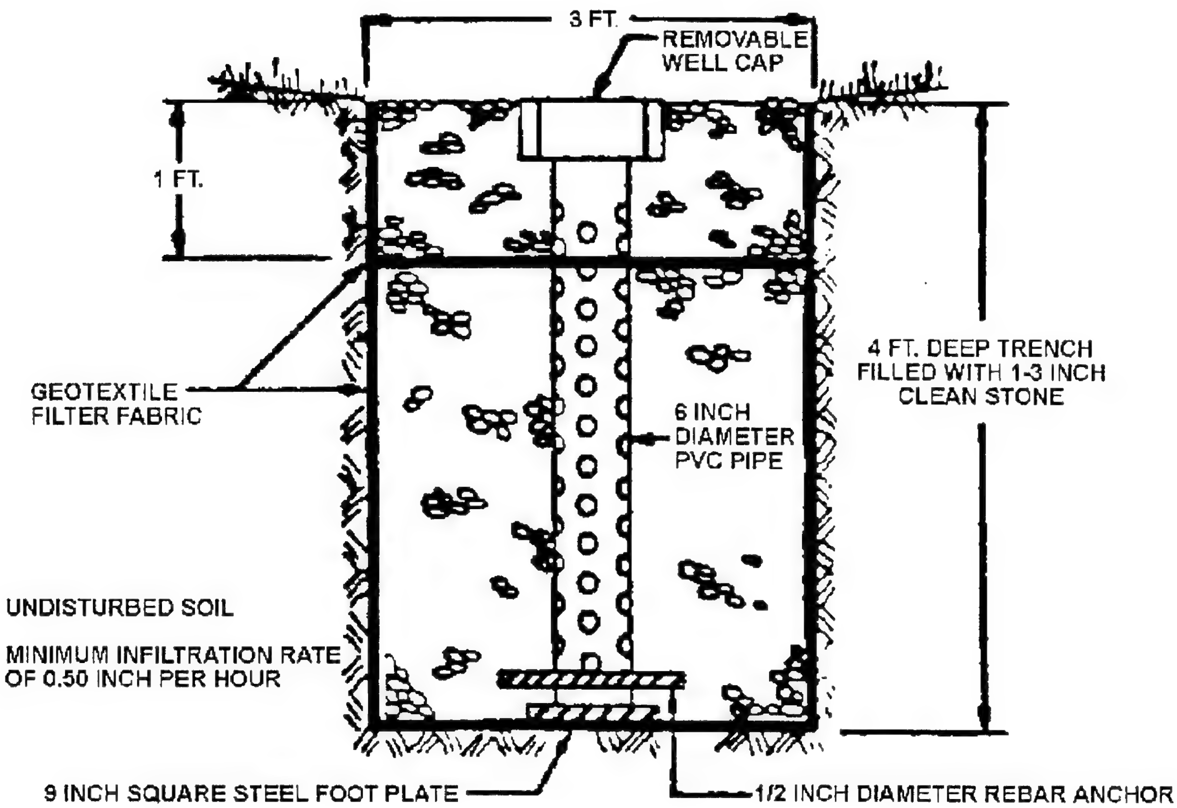
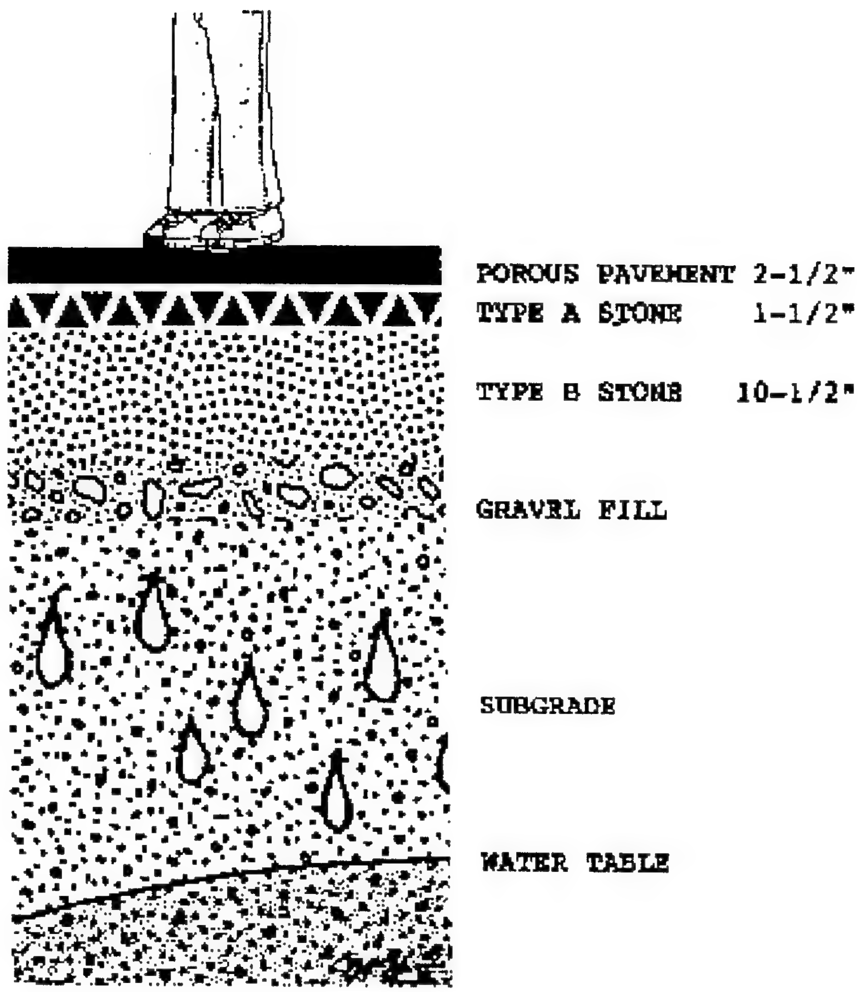


Figure 4: Constructed Wetlands (Botts, 1996)

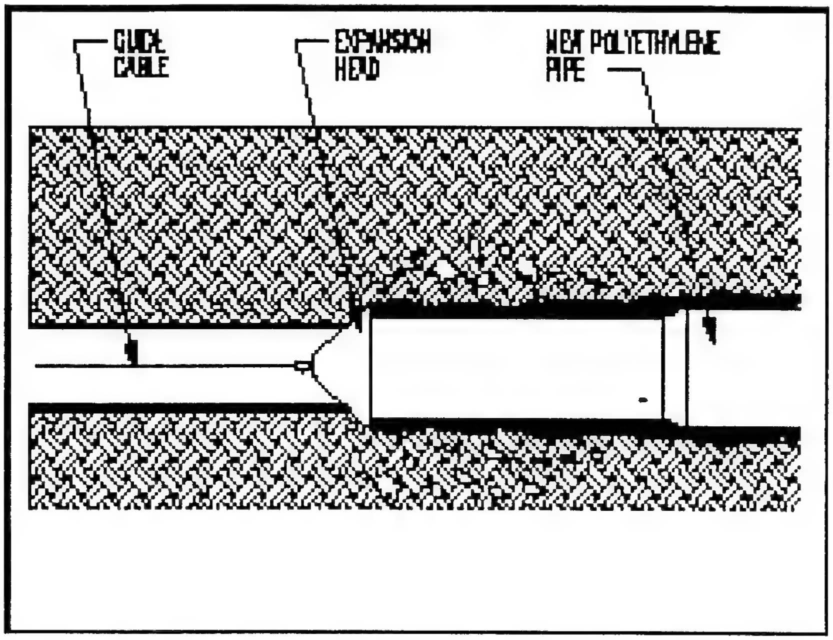


Source: SEWRPC.

Figure 5: Infiltration Trench (Botts, 1996)



<u>**Figure 6: Porous Pavement Cross Section (Botts, 1996)**</u>



Source: Created by Parsons Engineering Science, Inc., 1999

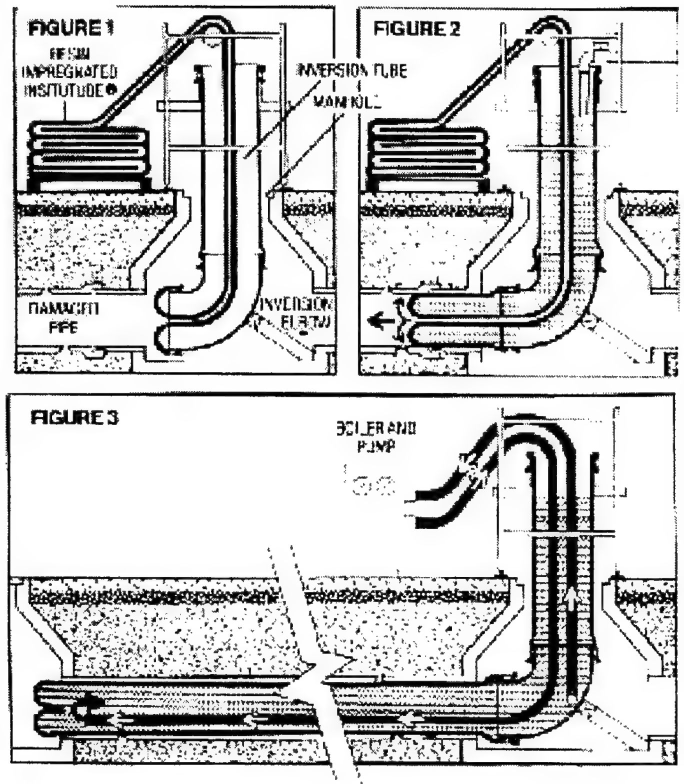
Figure 7: Pipe Bursting System (EPA, 1999)

How Insituform® is installed

Figure 1. A special needled felt reconstruction tube, Insitutube®, coated on the outside, is custom engineered and manufactured to fit the damaged pipe exactly. It is impregnated with a liquid thermosetting resin and lowered into a manhole through an inversion tube. One end of the Insitutube is firmly attached to the lower end of the inversion tube elbow.

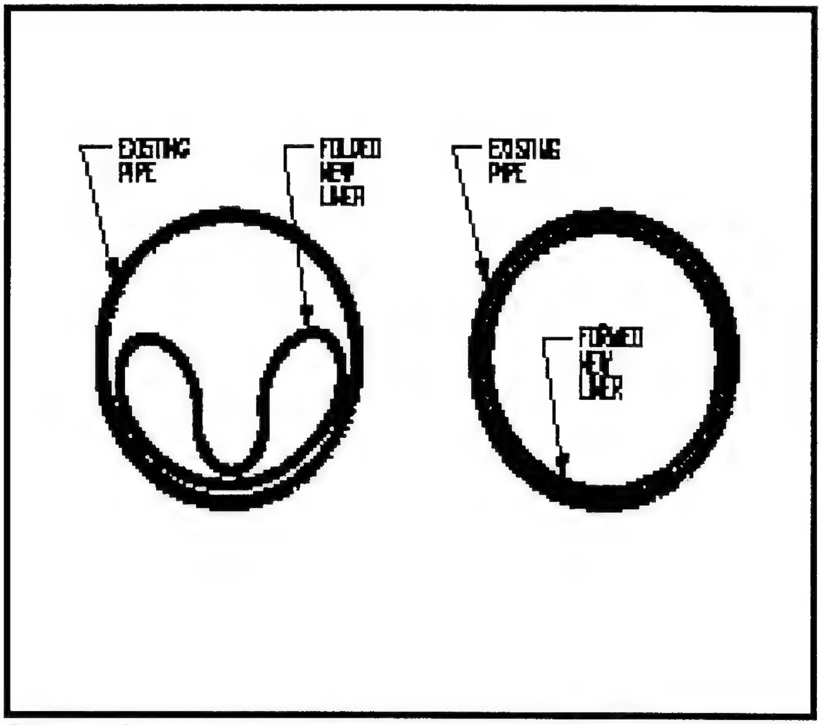
Figure 2. The inversion tube is then filled with water. The weight of the water pushes the Insitutube into the damaged pipe and turns it inside out, while pressing the resin impregnated side firmly against the inside walls of the old pipe. The smooth coated side of the Insitutube becomes the new interior surface of the pipe.

Figure 3. After the Insitutube is inverted through the old pipe to the desired length, the water is circulated through a boiler. The hot water causes the thermosetting resin to cure within a few hours, changing the pliable Insitutube into a hard, structurally sound, pipe-within-a-pipe, Insitupipe™. It has no joints or seams and is usually stronger than the pipe it replaced. The ends are cut off and the inversion tube and scaffolding are removed. Normally, there are no messy excavation repairs to be made since most work is done without digging or disruption.



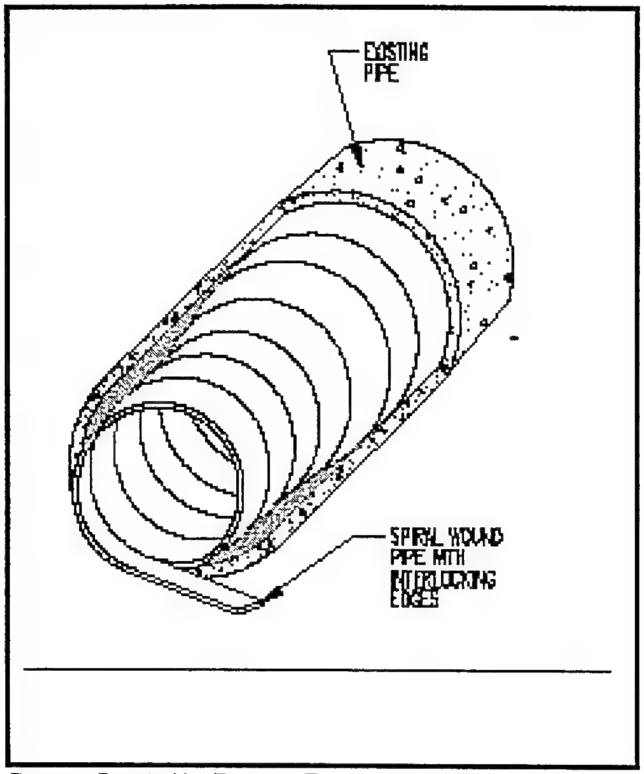
Source: Iseley and Najafi, 1995 (from Insituform®)

Figure 8: Cured In Place Pipe System (EPA, 1999)



Source: Created by Parsons Engineering Science. Inc.. 1999.

Figure 9: Modified Cross Sectional Lining (EPA, 1999)



Source: Created by Parsons Engineering Science, Inc., 1999

Figure 10: Spiral Wound Pipe System (EPA, 1999)

Table 1: State Stormwater Management Agencies

State	Regulating Organization	web page
Alaska	Alaska Department of Environmental Conservation	www.state.ak.us/local/akpages/ENV.CONSERV/dawq/dec_dawq.htm
Albama	Alabama Department of Environmental Management	www.adem.state.al.us/
Arizona	Arizona Department of Environmental Quality	www.adeq.state.az.us/
Arkansas	Arkansas Department of Environmental Quality	www.adeq.state.ar.us
California	California Department of Water Resources	www.water.ca.gov/
Colorado	Colorado Dept. of Public Health and Environment	www.cdphe.state.co.us/wq/wqhom.html
Conneticut	Conneticut Department of Environmental Protection	dep.state.ct.us/wtr/index.htm
Delaware	Dept. of Natural Resources and Environmental Control	www.dnrec.state.de.us/
Florida	Florida Department of Environmental Protection	www.dep.state.fl.us/water/division/standards/default.htm
Georgia	Department of Natural Resources	www.dnr.state.ga.us/dnr/environ/
Hawaii	Department of Land and Natural Resources	www.state.hi.us/dlnr/
Idaho	Idaho Department of Water Resources	www.idwr.state.id.us/
Illinois	Illinios Environmental Protection Agency	www.epa.state.il.us/water/index.html
Indiana	Indiana Department of Environmental Management	www.ai.org/idem/index.html
Iowa	Environmental protection division	www.state.ia.us/government/dnr/organiza/epd/wtrsuply/wtrsup.htm
Kansas	Kansas Department of Health and Environment	www.kdhe.state.ks.us/water/
Kentucky	Department of Environmental Protection	water.nr.state.ky.us/dow/dwhome.htm
Louisiana	Louisiana Department of Environmental Quality	www.deq.state.la.us/welcome.htm
Maine	Maine Department of Environmental Protection	janus.state.me.us/dep/blwq/
Maryland	Maryland Department of the Environment	www.mde.state.md.us/
Massachusetts	Department of Environmental Protection	www.state.ma.us/dep/dephome.htm
Michigan	Department of Environmental Quality	www.deq.state.mi.us/swq/
Minnesota	Department of Natural Resources	www.dnr.state.mn.us/waters/
Mississippi	Mississippi Department of Environmental Quality	www.deq.state.ms.us/newweb/homepages.nsf
Missouri	Department of Natural Resources	www.dnr.state.mo.us/water.htm
Montana	Montana Department of Environmental Quality	www.deq.state.mt.us/wqinfo/Index.htm
Nebraska	Department of Environmental Quality	www.deq.state.ne.us/Programs.nsf/pages/WQD
Nevada	Nevada Division of Enironmental Protection	www.state.nv.us/ndep/bwpc/bwpc01.htm
New Hampshire	Deparment of Environmental Services	www.des.state.nh.us/wmb/
New Jersey	Department of Environmental Protection	www.state.nj.us/dep/dwq/
New Mexico	New Mexico Environment Department	www.nmenv.state.nm.us/
New York	Department of Environmental Conservation	www.dec.state.ny.us/
North Carolina	Department of Environment and Natural Resources	h2o.enr.state.nc.us/
North Dakota	Division of Water Quality	www.health.state.nd.us/ndhd/environ/wq/index.htm
Ohio	Ohio Environmental Protection Agency	chagrin.epa.state.oh.us/
Oklahoma	Oklahoma Department of Environmental Quality	www.state.ok.us/~okag/wqhome.html
Oregon	Department of Environmental Quality	waterquality.deq.state.or.us/wq/
Pennsylvania	Pennsylvania Department of Environmental Protection	www.dep.state.pa.us/dep/deputate/watermgt/WC/Subjects/NonPoint.htm
Rhode Island	Department of Environental Management	www.state.ri.us/dem/org/waterres.htm
South Carolina	Department of Health and Environemntal Control	www.state.sc.us/dhec/
South Dakota	Deparment of Environment and Natural Resources	www.state.sd.us/state/executive/denr/DES/Surfacewater/surfwprg.htm

Table 1: State Stormwater Management Agencies (cont.)

State	Regulating Organization	web page
Tennessee	Department of Environment and Conservation	www.state.tn.us/environment/water.htm
Texas	Texas Natural Resource Conservation Comission	www.tnrcc.state.tx.us/
Utah	Department of Environmental Quality	www.deq.state.ut.us/eqwq/dwq_home.ssi
Vermont	Agency of Natural Reources	www.anr.state.vt.us/dec/water1.htm
Virginia	Department of Environmental Quality	www.deq.state.va.us/
Washington	Department of Ecology	www.wa.gov/ecology/wq/wqhome.html
West Virginia	Office of Water Reources	www.dep.state.wv.us/wr/OWR_Website/index.htm
Wisconsin	Department of Natural Resources	www.dnr.state.wi.us/org/water/wm/
Wyoming	Wyoming Department of Environmental Quality	www.wrds.uwyo.edu/wrds/deq/deq.html

Table 2: Constituents on Surface Waters (Ferguson, 1998)

Constituent	Role in Natural Ecosystem	Source of Urban Excess	Role of Excess
Sediment	Maintain stream profile and energy gradient; store nutrients	Construction sites, eroding stream banks, roads	Abrade fish gills; carry excess nutrients and chemicals in adsorption; block sunlight; cover gravel bottom habitats
Organic Compounds	Store nutrients	Car oil; herbicides, pesticides, fertilizer	Deprive water of oxygen by decomposition
Nutrients	Support ecosystems	Organic compounds; organic litter; food wastes; fertilizers; sewage	Unbalance ecosystem; produce algae blooms; deprive water of oxygen by decomposition
Trace Metals	Support ecosystems	Cars, construction materials; all kinds of foreign chemicals	Reduce resistance to disease; reduce reproductive capacity; alter behavior
Chloride	Support ecosystems	Pavement deicing salts	Sterilize soil and reduce biotic growth
Bacteria	Participate in ecosystems	Pet animals; trash handling areas; dumpsters;	Cause risk of disease
Oil	Store nutrients	Cars	Deoxygenate water

Table 3: Pollutant Removal Efficiencies of Best Management Practices (Dodson, 1999)

BMP	Nutrients	Sediment	Metals	BOD & COD	Oil and Grease	Bacteria
Dry Detention Basin	Low	High	Moderate	Moderate	Low	High
Infiltration Devices	High	Very high	Very high	Very high	High	Very high
Sand Filters	Moderate	Very high	Very high	Moderate	High	Moderate
Oil and Grease Traps	None	Low	Low	Low	High	Low
Vegetative Practices	Low	Moderate	Moderate	Low	Moderate	Low
Constructed Wetlands	High	Very high	High	Moderate	Very high	High
Wet Ponds	Moderate to High	High	Moderate to High	Moderate	High	High

Table 4: Typical Cost Range for Small Sewer Mains (EPA, 1999)

Technique	Pipe Diameter, in.	Cost Range, per linear foot
Pipe Bursting	8	$40 - $80
Sliplining	21	$80 - $170
Cured-in-Place Pipe	8	$25 - $65
Modified Cross Section	8	$18 - $50

Table 5: Pipeline Rehabilitation Renovation Options (ASCE, 1994)

Rehabilitation Option	Principal Advantages	Principal Disadvantages	Potential application
Continuous pipe sliplining	Quick insertion Large-radius bends accommodated	Circular cross section only Insertion trench disruptive High loss of area in smaller sizes Less cost effective where deep	4 to 63 in.
Short pipe sliplining	High strength-to-width ratio Variety of cross sections can be manufactured Minimal disruption	Some materials easily damaged during installation Larger pipes may require temporary support during grouting May involve labor-intensive jointing	4 to 144 in.
Cured-in-place pipe	Rapid installation No excavation Accommodates bends and minor deformation Maximizes capacity Grouting not normally necessary	Full bypass pumping necessary Sole source often necessary High set-up costs on small projects	4 to 108 in.
U-liner/Nu-pipe deformed pipe	Rapid installation Continuous pipes Maximizes capacity No excavation Grouting not required	Lateral relocation may be difficult Relies on existing pipe for support	2.5 to 24 in.
Roll down/swage lining preformed pipe	Rapid installation Maximizes capacity Minimal excavation Grouting not required	Lateral relocation may be difficult Relies on existing pipe for support	3 to 24 in.
Spiral-wound pipe	Tailor-made inside the conduit No excavation required Maximizes capacity Rapid installation Noncircular available	Large number of joints Relies on existing pipe for support Requires careful grouting of annulus	3 to 120 in.
Coatings-gunite/shotcrete	Connections easily accommodated Zero/minimal excavation Variety of cross sections possible	Difficult to supervise May be labor intensive Control of infiltration required	4 ft and larger

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